Slurry Retrieval, Pipeline Transport & Plugging, and Mixing Workshop

Gravity Flow Systems

River Protection Project

WASTE TREATMENT PLANT

MN Hall
1-16-98

Department of Energy

Office of River Protection

Bechtel National, Inc.

Examples of WTP Gravity Flow Systems

- Internal Process Lines (pitch from high point to both source and receiver vessels after transfer)
  - 3-inch to 24-inch lines
  - Feed Receipt lines
- Breakpots (Steam ejectors to high point, vents steam, then gravity flow to receiver vessel)
- Flush to Drain (change of fluid, solids build up, plug removal)
- Floor and Fire water drains (C2, C3 and C5 areas)

Chemical Plugging

- BNI Design Guide

24590-WTP-GPG-M-0059, Rev 0
Avoiding Chemical Line Plugging - Plant Design Considerations
Effective Date: 15 November 2007

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Design Guide:

Avoiding Chemical Line Plugging - Plant Design Considerations

Contents

WTP Gravity Flow

- 1 to 21 cP , Newtonian Slurries with less than 5% solids
- Fill factors 50 to 70% (vented flow)
- Typical slopes
  - 1/100
  - 1/50
  - 1/20

Gravity Flow Methodology

Section 1 - Critical Flow

$g := 32.2$

Schedule 40 S Pipe

1 inch
1 1/2 inch
2 inch
3 inch
4 inch
6 inch
8 inch
10 inch
12 inch

Fill Factor is equal to: $F = \frac{y}{D} = \%$ Defined Fill Factor $F := \frac{70}{100}$

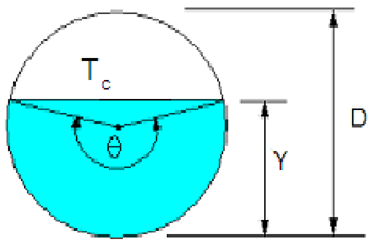
$\theta := 2 \cdot \mathrm{acos}(1 - F \cdot 2)$ $\theta = 3.965$ rads

$d = 7.981$ in

$D := \frac{d}{12}$

$A_c := \frac{(D)^2}{8} \cdot (\theta - \sin(\theta))$ $A_c = 0.26$ ft^2

$T_c := D \cdot \sin\left(\frac{\theta}{2}\right)$ $T_c = 0.6096$ ft



$Q_c := 1$

Given $\frac{{A_c}^3}{T_c} = \frac{{Q_c}^2}{g}$ $Q_{gpm} := \mathrm{Find}(Q_c) \cdot 448.83$ $Q_{gpm} = 431.9$ gpm

Pipe Throat Velocity $V_c := \frac{\frac{Q_{gpm}}{448.83}}{A_c}$ $V_c = 3.7$ $\frac{ft}{s}$

Liquid Surface Height $E := \left(D \cdot F + \frac{{V_c}^2}{2 \cdot g}\right) \cdot 12$ $E = 8.1435$ in

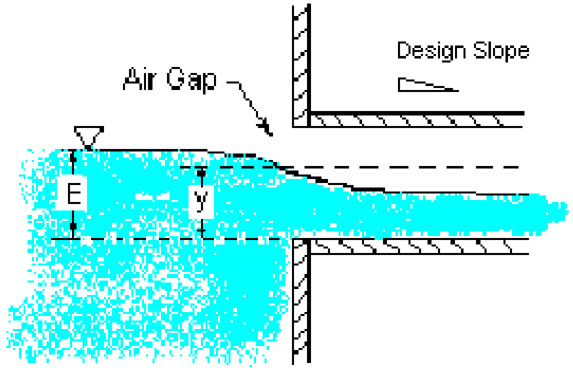


Figure Overflow Inlet

Gravity Flow Systems

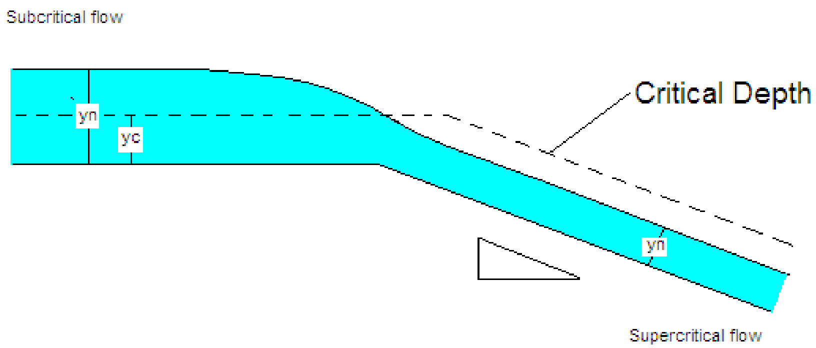
Critical Slope

Assumed Manning's n $n := .011$ $Q_{cfs} := \frac{Q_{gpm}}{(448.83)}$

Hydraulic Radius: $R_h := \frac{2 \cdot A_c}{\theta \cdot D}$ $R_h = 0.19702 \text{ ft}$ $S_c := 1$

Manning Equation: Given $Q_{cfs} = \frac{1.49}{n} \cdot A_c \cdot R_h^{\frac{2}{3}} \cdot S_c^{\frac{1}{2}}$ $S_c := \text{Find}(S_c)$ Uses Critical Flow and Area as input - Result is critical slop

$S_c = 0.00652$ **Critical Slope:** $\frac{1}{S_c} = 153$ The Critical Slope is the slope that the pipe would have to be at if the surface level anc the bottom of the pipe were equal. (Lquid surface was at the hydraulic gradiant.)



Gravity Flow Systems

Section 3 - Supercritical Flow and Fill Factor

The Manning equation, substituting equations from Section 1 for A_c, and R_h from Section 2. Design Slope: $S_d := \frac{1}{20}$

$$\text{Given} \quad Q_{cfs} = \frac{1.49}{n} \cdot \left[\frac{D^2}{8} \cdot (\theta - \sin(\theta))\right] \cdot \left[\frac{2 \cdot \left[\frac{D^2}{8} \cdot (\theta - \sin(\theta))\right]}{\theta \cdot D}\right]^{\frac{2}{3}} \cdot S_d^{\frac{1}{2}} \qquad \theta := \mathrm{Find}(\theta)$$

$$A_c := \frac{D^2}{8} \cdot (\theta - \sin(\theta))$$

Velocity At Supercritical Flow : $V_{c2} := \frac{Q_{cfs}}{A_c}$ $\quad V_{c2} = 8.02 \ \frac{ft}{s}$

$$\text{Given} \quad \theta = 2 \cdot \mathrm{acos}(1 - F \cdot 2) \qquad F_{sc} := \mathrm{Find}(F) \cdot 100$$

Fill Factor % at Supercritical Flow : $F_{sc} = 37.7$ %

New Wetted Perimeter: $\theta \cdot D = 1.759$ ft

$$\text{given} \quad \theta \cdot D = \pi \cdot D_2 \qquad D_2 := \mathrm{find}(D_2) \cdot 12 \qquad D_2 = 6.72 \ \text{in}$$

Stationary Bed Formation

Initial guess for critical velocity: $Vcr := 1\dfrac{ft}{sec}$

Given

$$Vcr = \left| \begin{array}{l} Cs\mu \leftarrow \dfrac{Cwt}{\dfrac{\rho s}{\rho L} - \left(\dfrac{\rho s}{\rho L} - 1\right)\cdot Cwt}\cdot\left(\eta_{homo}\right)\cdot\eta 1 \\ Cs \leftarrow \dfrac{Cwt}{\dfrac{\rho s}{\rho L} - \left(\dfrac{\rho s}{\rho L} - 1\right)\cdot Cwt}\cdot\left(1 - \eta_{homo}\right)\cdot\eta 1 \\ \mu M \leftarrow 2\cdot\left[1 + 2.5\cdot Cs\mu + 10.05\cdot Cs\mu^{2} + 1.3\cdot\left(\exp\left(17\cdot Cs\mu\right) - 1\right)\right]\cdot\left(\dfrac{8\cdot Vcr\cdot\dfrac{sec}{m}}{\dfrac{D}{m}}\right)^{-0.06} \\ F \leftarrow \sqrt{9.81\dfrac{dp}{m}\cdot\left(\dfrac{\rho s}{\rho L} - 1\right)} \\ (F)\cdot 1.85\cdot Cs^{0.1536}\cdot(1 - Cs)^{0.3564}\cdot\left(\dfrac{\dfrac{dp}{m}}{\dfrac{D}{m}}\right)^{-0.378}\cdot\left[\dfrac{\dfrac{D}{m}\cdot\rho L\cdot\dfrac{m^{3}}{kg}\cdot(F)}{\dfrac{\mu M}{1000}}\right]^{0.09}\cdot\chi^{0.3}\cdot(1 + M)\cdot\dfrac{m}{sec} \end{array}\right.$$

Homogeneous Solids Fraction

Heterogeneous Solids Fraction

Viscosity Adjustment (RPP-9805, Section 6)

OT Equation

$$Vcr\left(D, dp, \rho s, \rho L, Cwt, \chi, M, \eta_{homo}, \eta 1\right) := Find(Vcr)$$

Velocity Check

Affective Pipe diameter:	$D := 6.72\,in$	From Critical Flow Estimate
Particle diameter:	$dp := 210 \times 10^{-6}\,m$	
Solids density:	$\rho s := 2180 \frac{kg}{m^3}$	
Liquid density:	$\rho L := 1100 \frac{kg}{m^3}$	
Solids weight percent:	$Cwt := 16.7\%$	
Fraction of eddies with velocities exceeding the hindered settling velocity of solids:	$\chi := 0.95$	
Design margin:	$M := 0\%$	
Solids Homogenous Fraction:	$\eta_{homo} := 75\%$	74 micron fines/coarse
Solids in pipe at start of flow:	$\eta 1 := 100\%$	$Vcr(D, dp, \rho s, \rho L, Cwt, \chi, M, \eta_{homo}, \eta 1) = 3.584 \frac{ft}{sec}$

Critical Flow = 8.2 ft/s   or 128% margin